HEAT TRANSMISSION IN A VACUUM EVAPORATOR

BY
H. C. DORMITZER
E. P. ROLESON

ARMOUR INSTITUTE OF TECHNOLOGY

1912

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Heat transmission in a
vacuum evaporator

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A THESIS

PRESENTED BY

H.C.DORMITZER AND E.P.ROLESON

TO THE

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OF THE

ARMOUR INSTITUTE OF TECHNOLOGY

FOR THE DEGREE OF

BACHELOR OF SCIENCE IN CHEMICAL ENGINEERING

HAVING COMPLETED THE PRESCRIBED

COURSE OF STUDY IN

CHEMICAL ENGINEERING

1912

APPROVED H McCormack
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HEAT TRANSMISSION IN A VACUUM EVAPORATOR

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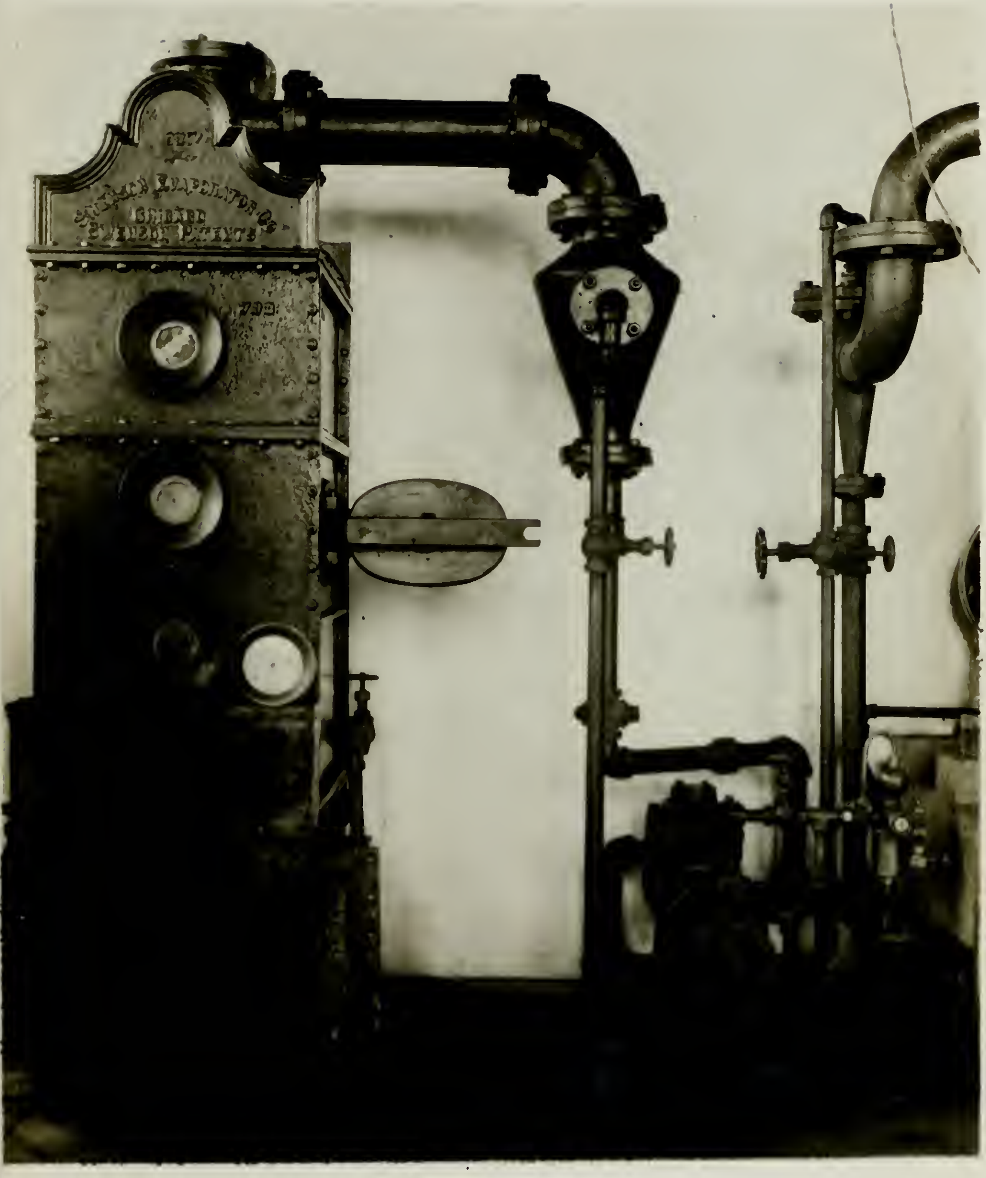

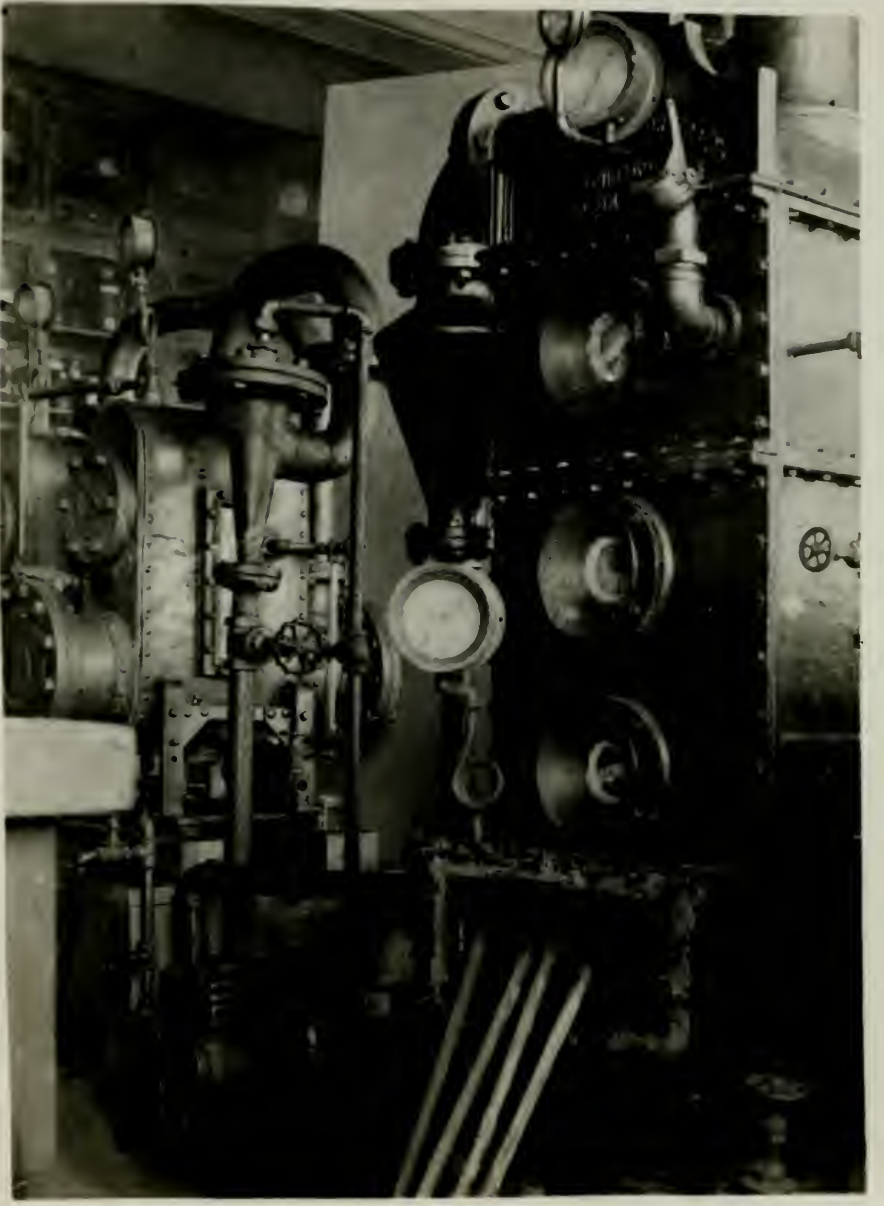

to the weighing tank. Thirty-two steam tubes were used in each

The object of this series of experiments was to determine the efficiencies of a Swenson Evaporator using tubes of four different materials,namely copper,steel,lead and tin. In order that the results of these tests may be comparable with the work of other investigators,the conditions were carefully recorded. It is known that slight variations in the composition of the metal (impurities) exert considerable influence on the conductivity for heat. In view of this fact,the tubes were carefully sampled and analyzed by standard methods. The auxiliary apparatus,such as scales,gauges,thermometers,etc,was tested for accuracy and the necessary corrections made. The steam gauge was tested on a Crosby Steam Gauge Tester and the vacuum gauge was calibrated against a mercury column. The scales used for weighing the water necessary were compared with a standard balance. The thermometers were checked up against a thermometer standardized by the U.S.Government Bureau of Standards.

APPARATUS

The evaporator used was of the single effect Swenson type, especially designed for experimental purposes. The dimensions and details are clearly shown by the blue-print which forms a part of this report. The general arrangement of piping and auxiliary apparatus is shown by two photgraphs ,accompanying. The walls of the evaporator are of one half inch cast iron bolted with three-eighths bolts. The steam enters the steam chest by means of a three quarter inch pipe,passes through the heating tube into the exhaust chamber and flows out through a one inch drain in to the weighing tank. Thirty-two steam tubes were used in each

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test. The tubes are fitted into holes bored in the plate separating the steam chest from the body of the evaporator proper, and made steam tight by rubber gaskets. The whole is held firmly in place by cast iron plates bolted to the frame.

The vapors are led to the condenser by a five inch cast iron pipe,condensed by a spray of cold water and drawn off by a steam pump. The pump is made by the American Steam Valve and Pump Co.,and has dimensions as follows,-

Steam cylinder	diameter	4 inches
Water cylinder	diameter	3 inches
Piston rod	diameter	7/8 inches
Stroke		6 inches

The cooling water and condensed steam were collected in weighing tanks and the amount recorded.

METHOD

The cold evaporator was filled with water to a depth of two inches above the tubes and a preliminary run made to heat up the apparatus. The time necessary for this run averaged twenty minutes. When one run was started immediately after the close of the one preceding,this preliminary heating was unnecessary. When the evaporator was thoroughly heated the water was taken out and a weighed amount of hot water put in. One hundred and eighty pounds was found to fill the evaporator to the desired level. At a definite time,the temperature of the water was taken and the evaporator closed for the run. The exhaust valve was opened a measured amount and the steam valve opened sufficiently

to give the desired pressure,ranging between five and ten pounds gauge pressure. The pump is started and the cooling water turned on. Readings of steam pressure,vacuum and the temperature of the exhaust steam were taken every five minutes. Each run lasted two hours. In order to keep the water level in the evaporator constant,water in measured amounts at definite temperatures was added as needed. In order to keep the condensed steam from evaporating, cold water in measured amounts was added to the container. At the end of the run the pump, cooling water and live steam were turned off and the steam tubes allowed to drain. The water remaining in the evaporator was weighed and its temperature taken. This cycle of operations was repeated for each run.

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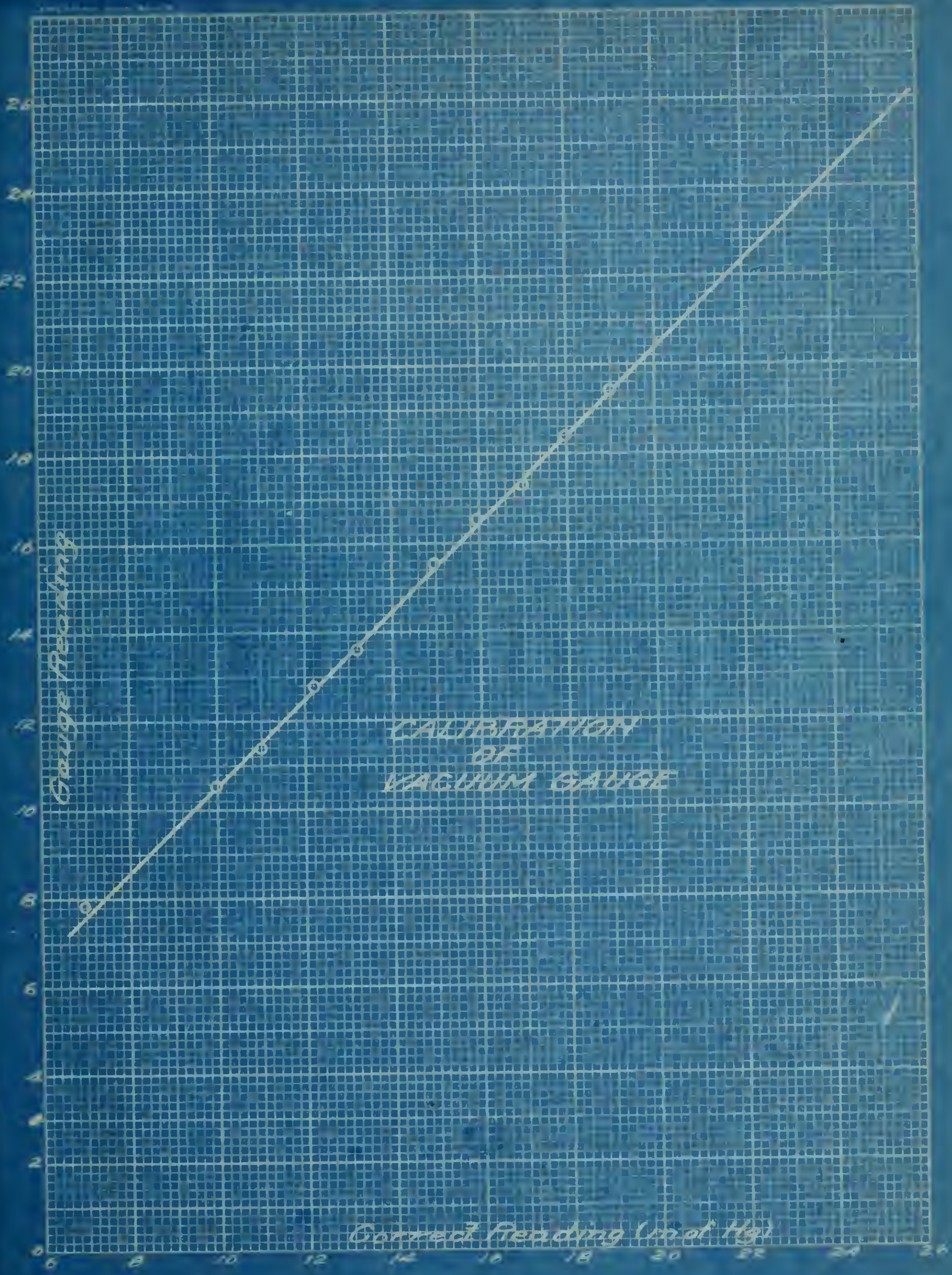
CALIBRATION OF VACUUM GAUGE.
By comparison with mecury column.

Maker and number of gauge Schaffer & Budenberg

Observer H.C.Dormitzer,E.P.Roleson.

No.	MERCURY COLUMN		GAUGE READINGS								ERROR	
	Inches	Pounds	BEFORE ADJUSTMENT				AFTER ADJUSTMENT				BEFORE ADJUSTMENT	AFTER ADJUSTMENT
			INCHES			POUNDS	INCHES			POUNDS		
			Up	Down	Mean		Up	Down	Mean			
1	19.0		19.3									
2	18.0		18.4									
3	17.0		17.2									
4	16.0		16.5									
5	15.0		15.5									
6	14.25		14.8									
7	13.25		13.8									
8	12.25		12.8									
9	11.0		11.4									
10	10.0		10.5									
11	7.0		7.8									

No attempt was made to correct the gauge. The readings were corrected by means of a curve plotted from the data. The curve is attached.


CALIBRATION
OF
VACUUM GAUGE
Gauge Reading
Correct Reading (in of Hg)
26
24
22
20
18
16
14
12
10
8
6
4
2
0
6
8
10
12
14
16
18
20
22
24
26

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Date 5-3-'12

CALIBRATION OF PRESSURE GAUGE.

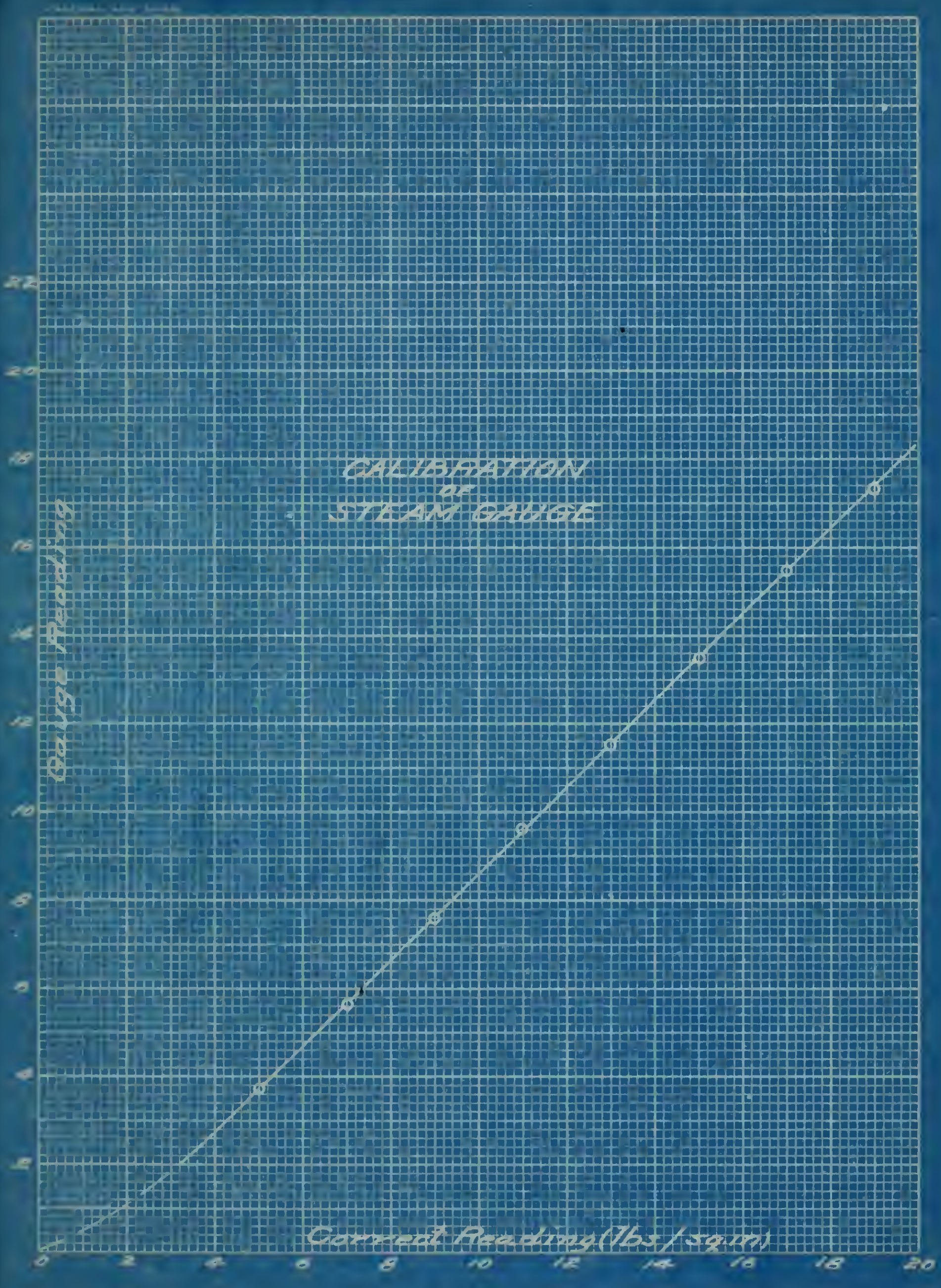
By comparison with Square Inch Gauge Tester.

Maker and number of gauge Schaffer & Budenberg

Observer H.C.Dormitzer,E.P.Roleson

NUMBER	READING GAUGE TESTER POUNDS	GAUGE READING IN POUNDS						ERROR	
		BEFORE ADJUSTMENT			AFTER ADJUSTMENT			BEFORE ADJUSTMENT	AFTER ADJUSTMENT
		UP	DOWN	MEAN	UP	DOWN	MEAN		
1	5	3.8	3.7	3.75					
2	7	5.6	5.6	5.6					
3	9	7.6	7.6	7.6					
4	11	9.7	9.6	9.65					
5	13	11.6	11.5	11.55					
6	15	13.4	13.5	13.45					
7	17	15.4	15.5	15.45					
8	19	17.3	17.3	17.3					
9	21	19.3	19.3	19.3					
10	23	21.2	21.2	21.2					
11	25	23.0	23.1	23.05					
12	27	25.0	25.0	25.0					
13	29	26.9	26.8	26.85					
14	31	28.9	28.9	28.9					

No attempt was made to correct the gauge. The readings were corrected by means of a curve plotted from this data. The curve is attached.


CALIBRATION
OF
STEAM GAUGE
Gauge Reading
22
20
18
16
14
12
10
8
6
4
2
Correct Reading (lbs / sq.in)
0
2
4
6
8
10
12
14
16
18
20

METHODS OF ANALYSIS

In making the analyses of the four sets of tubes used in this set of tests, the best available methods were used. It was necessary to determine carbon, sulphur, phosphorus and manganese in the steel; to determine copper, copper oxide, lead, tin, and zinc in the copper tubes; to determine tin, lead, antimony and zinc in the tin tubes and to determine lead, antimony, tin and zinc in the lead tubes. In order to save space the analyses of the last three tubes will be described as though they were alloyed and an analysis of this alloy had to be made.

Carbon is determined by the color method. 0.5 gm. duplicates of the sample and the standard are weighed into test tubes of about 30 cc. capacity. 15 cc. of nitric acid (sp. gr. 1.2) is added to each test tube. The tubes are put in a metal beaker of about 600 cc. capacity and boiled for ten minutes. At the end of this time everything should be in solution. If, on account of the large size of the samples, they will not dissolve in this time, boil them longer. The sample and standard should be boiled an equal length of time. The two are compared in the regular colorimetric tubes and the % carbon in the sample figured directly.

Sulphur is determined by the evolution method. 5 grams of the sample and an equal amount of the standard are weighed into 500 cc. Erlenmeyer flasks. 150 cc. of HCl (1 - 1) is added through a thistle tube, which projects below the level of the acid in the Erlenmeyer. The hydrogen generated, carrying with it the H_2S formed from the sulphur compounds of the steel, passes through a glass tube into an absorption flask, in which has been placed 30 cc

of a ten per cent solution of cadmium chloride, containing at least twenty per cent of ammonium hydroxide. The flask is gently heated until all the steel is in solution. The contents are then brought to a boil and the connection between the flask and the absorption bulb broken as soon as the condensed steam commences to drip into the bulb. The contents of the absorption flask are made acid with HCl after the addition of a slight excess of N/20 iodine solution. The blue color, which appears on the addition of starch solution, is discharged with N/20 sodium thio-sulphate. The % of sulphur in the sample is determined by direct comparison with the standard which is run at the same time.

Phosphorus is titrated with sodium hydroxide solution. 5.0 grams of the steel is weighed into a 500 cc. Erlenmeyer flask, and is dissolved in nitric acid (1 - 2) by gentle heating. When solution is complete, enough of a saturated solution of potassium permanganate is added to give a permanent heavy brown precipitate. The solution is boiled to ensure complete oxidation, cooled slightly and the manganese dioxide dissolved by adding a pinch of sugar. The solution is cooled to room temperature and enough ammonium hydroxide added to make the solution an amber color. This should bring the temperature to about 60 °C. 50 cc. of an ammoniacal solution of molybdic acid is added and the flask shaken well. The precipitated phospho molybdate is filtered off, washed free from nitric acid and triturated with standard sodium hydroxide.

Manganese is determined by Ford's method. 5.0 grams of the steel is weighed into a 500 cc. beaker and dissolved in nitric acid (1 - 1). 100 cc. of nitric acid (sp.gr. 1.42) and 10 grams of potassium chlorate are added and the solution boiled until the pre-

cipitation of manganese dioxide is complete. The manganese dioxide is filtered out on asbestos, using a suction pump, dissolved in a definite amount of standard ferrous sulphate solution and the excess of ferrous sulphate solution titrated with potassium permanganate.

ALLOY

Antimony and tin are weighed together as the oxides, and the amount of antimony determined on a separate sample. The alloy is dissolved in nitric acid (sp.gr.1.2) and evaporated to moist dryness. The beaker is allowed to cool and cold distilled water added in large quantities, at least 75 cc. The oxides are filtered out, the filter paper dried and placed in a crucible. The crucible is heated slowly until all the carbon is consumed, and then at a dull red heat to constant weight.

Antimony is titrated in a separate sample with $KMnO_4$ solution. It is necessary to standardize the permanganate solution against antimony, as the theoretical antimony value does not agree with that actually obtained. The variation is slight but is sufficient to cause some error. Weight of antimony in sample in proportion to tin must be known approximately, and this proportion maintained in the standardization. Weigh 0.1202 grams powdered CP antimony into a 500 cc. Erlenmeyer. Add the proper amount of CP tin. Add 3 gm. K_2SO_4 and 10 cc. H_2SO_4)1.84). Heat to solution over a small naked flame. Cool, add 50 cc. distilled water and 2 grams tartaric acid. Heat to boiling and boil for 5 minutes. Cool, add 110 cc. water and 25 cc. HCl (1.2 sp.gr.) Titrate with $KMnO_4$ to first permanence of pink color throughout the solution.

Lead is determined in the filtrate from the combined oxides. 10 cc. of conc. sulphuric acid is added after filtering out

the oxides and the solution evaporated to dryness or to copious fumes of sulphuric anhydride. The lead sulphate is filtered out on a gooch crucible,washed with a dilute sulphuric acid solution and alcohol,dried and weighed. The residue is made alkaline with ammonia and any copper noted by the presence of a blue color. Iron and aluminum if present will precipitate at this point and may be filtered out and weighed in the usual manner. If any copper is present it will be determined as the sub-iodide. The ammoniacal solution is acidified with acetic acid,and sulphurous acid added to excess. Fifty cc.of 10% potassium iodide solution is added and the solution boiled until the precipitate becomes granular. It is then filtered on a gooch crucible and weighed as CuI;the % of copper being calculated directly.

Zinc is determined in the filtrate from the copper. The solution is made ammoniacal,after boiling out the sulphurous acid. It is quite frequently necessary to filter at this point owing to the precipitation of sulphur. The solution is made barely acid with hydrochloric acid,and 50 cc.of sodium ammonium phosphate added. The zinc is precipitated as zinc ammonium phosphate,$Zn_2P_2O_7$. The precipitate is granulated by boiling,filtered out,and ignited in a porcelain crucible.

Data on tubes

Steel

Carbon	0.10 %	Average outside diameter	19.02 mm
Manganese	0.39	Average inside diameter	16.56
Sulphur	0.02		-----
Phosphorus	.016		2.46
		Average thickness	1.23 mm

Copper

Copper	99.92 %	Average outside diameter	19.00 mm
		Average inside diameter	16.41
No impurities			-----
			2.59
		Average thickness	1.29 mm

Lead

Antimony	9.6 %	Average outside diameter	19.98 mm
Lead	90.2	Average inside diameter	12.61

No other metals			7.37
		Average thickness	3.68 mm

Tin

Antimony	0.4 %	Average outside diameter	19.01 mm
Tin	99.6	Average inside diameter	12.61

			6.40
		Average thickness	3.20 mm

The actual length of the tubes is 25 inches.

The effectual length(in contact with water) is 24 inches.

Copper tubes - first run

Time-Hours Minutes	Steam pressure Pounds - gauge	Vacuum Inches Hg	Temperature Exhaust steam
0:00	10.0	20.0	80 °C.
5	10.2	20.8	80.0
10	9.5	23.0	79.0
15	10.9	23.3	75.0
20	10.2	23.8	72.0
25	10.0	24.0	71.0
30	9.8	24.1	69.5
35	10.2	24.1	70.0
40	10.5	23.9	70.0
45	7.0	24.0	76.0
50	10.2	23.5	76.0
55	7.2	23.9	76.5
1:00	7.9	23.8	78.5
5	8.5	23.5	79.0
10	9.0	23.9	78.0
15	10.2	23.9	75.0
20	11.5	23.8	76.0
25	12.3	23.7	76.0
30	11.8	23.8	75.0
35	11.5	24.0	77.0
40	11.1	24.0	76.0
45	9.8	24.2	72.0
50	10.8	24.1	75.0
55	12.5	24.1	77.0
2:00	16.1	24.1	76.0

Water added #		Water removed #	Condensed steam #	Cold water added to condense steam #
180 at	50 °C	92.5 #	24.5	30.0
26	57.5		29.0	30.0
25	51		26.0	30.0
26.7	60		24.5	30.0
27	62		26.0	
28.5	50		26.7	
22.5	51		27.0	
			25.0	
			27.5	
			24.0	
			22.5	
			20.5	
			23.0	
			24.0	
			22.5	
			20.5	
			23.0	
			24.0	
			24.5	
			25.5	
			26.5	

Copper tubes - first run

Average steam pressure - gauge		10.3 #
- corrected		11.8
- absolute		26.5
Quality of steam		95.0 %
Latent heat of vaporization at 26.5 #		949.2 B.T.U./#
Temperature of steam at 26.5 #		243.7 ° F.
Average temperature of exhaust steam	75.4 C	167.7 ° F
Gross weight condensed steam		426.7 #
Water added to condense steam		120.0 #
Net weight condensed steam		306.7 #

Heat given up by steam cooling 243.7°- 167.7° (76 ° F)

306.7 x 76 - 23,300

Heat given up by steam condensing

306.7 x 95 % x 949.2 - 276,600

Heat used (B.T.U.) 299,900

Average vacuum in evaporator - gauge	23.6 " Hg.
- corrected	23.2
- pounds absolute	3.3 #
Latent heat of vaporization at 3.3 #	1010.0 B.T.U.
Temperature at boiling point - 3.3 # pressure	145.3 ° F

Heat used to raise water added to boiling point

180 #	at 50 C -	122 F	180 x	23.3 -	4200
26	at 57.5	135.5	26	9.8 -	250
25	at 51	123.8	25	21.5 -	540
26.7	at 60	140.0	26.7	5.3 -	140
27	at 62	143.6	27	1.7 -	50
28.5	at 50	122	28.5	23.3 -	670
22.5	at 51	123.8	22.5	21.5 -	490

					6340 B.T.U.

Total water added	335.7 #
Water removed	92.5
Water evaporated	243.2

Heat used to vaporize 243.2 # of water

243.2 x 1010 = 245,600 B.T.U.

Total heat used 251,940 B.T.U.

Efficiency 83.8 %

Copper tubes - second run

Time Hours Minutes	Steam pressure Pounds - gauge	Vacuum Inches Hg	Temperature Exhaust`steam
0:00	5.5	24.0	174 ° F
5	5.3	23.6	173
10	7.0	24.6	169
15	7.4	24.5	170
20	7.9	24.5	170.5
25	8.6	24.3	170
30	7.8	24.0	167
35	7.3	24.1	165.5
40	6.2	24.1	165
45	7.5	24.2	165
50	6.5	22.8	168
55	6.0	23.7	168
1:00	8.1	24.1	168
5	6.2	23.3	178
10	5.7	23.0	172
15	3.8	24.2	163
20	7.2	24.3	108
25	11.0	24.1	182
30	10.4	23.6	185
35	9.0	24.0	185
40	12.5	20.6	195
45	7.5	22.1	181
50	9.7	23.9	179
55	13.4	23.3	185
2:00	15.0	23.0	186

Water added #	at ° F	Water removed	Condensed steam #	Cold water added to condense steam
180	142 F	129.5 #	28.5	30 #
25.5	138.5		25.5	30
27.5	142		27.7	30
24.2	139		25.5	
25	133		24.2	
25	138.5		25.0	
26	148		25.0	
24	153		26.5	
25.5	151		27.5	
23	143		25.0	
			24.0	
			25.5	
			23.0	
			22.5	
			24.0	
			24.5	
			29.5	

Copper tubes - second run

Average steam pressure - gauge	8.1	#
- corrected	9.4	
- absolute	24.1	
Quality of steam	95.0	%
Latent heat of vaporization at 24.1 #	952.7	B.T.U.
Temperature of steam at boiling 24.1 #	238.0	°F
Average temperature of exhaust steam	174.1	
Gross weight condensed steam	433.4	
Water added to condense steam	90.0	
Net weight condensed steam	343.4	

Heat given up by steam in cooling from 238.0 to 174.1 or 63.9 °F

343.4 x 63.9 - 21,940 B.T.U.

Heat given up by steam condensing

0.95 x 343.4 x 952.7 - 310,700

Total 332,640

Average vacuum in evaporator - gauge	23.7	" Hg
- corrected	23.2	" Hg
- # absolute	3.3	#
Latent heat of vaporization at 3.3 #	1010.0	B.T.U.
Boiling temperature at 3.3 #	145.3	°F
Total water added	405.7	#
Water removed	129.5	
Water evaporated	276.2	

Heat to raise added water to boiling temperature

180 #	at 142 °F	180	x 3.3	- 595			
25.5	138.5	25.5	6.8	173			
27.5	142	27.5	3.3	91			
24.2	139	24.2	6.3	152			
25	138.5	25	6.8	170			
25	133	25	12.3	310			
26	148				26	x 2.7	- 70
24	153				24	7.7	185
25.5	151				25.5	5.7	145
23.	143	23	2.3	53			---
				---			400
				1554			

Heat to vaporize 276.2 # 279,000

Total 280,150

Efficiency 85.2 %

Copper tubes - third run

Time - Hours Minutes	Steam pressure Pounds - gauge	Vacuum Inches Hg.	Temperature Exhaust steam
0:00			
5	11.0	23.5	169
10	8.5	25.0	156
15	9.0	25.1	156
20	8.5	25.0	156
25	7.8	25.0	159
30	6.9	24.5	155
35	7.3	24.5	163
40	6.2	24.5	164
45	8.5	24.2	166
50	9.5	24.2	170
55	8.5	24.5	167
1:00	12.0	24.2	174
5	10.1	24.9	170
10	6.0	25.1	165
15	10.6	25.0	174
20	8.6	24.5	170
25	8.5	25.0	167
30	9.5	25.0	168
35	10.1	25.1	168
40	10.8	25.1	168
45	10.8	24.8	169
50	11.1	24.9	167
55	11.3	24.9	167
2:00	11.8	24.7	169

Water added at --- °F		Water removed	Condensed steam	Cold water added to condense steam
180 # at	144°	169 #	27.5 #	30 #
27.5	122		25.0	30
25	129		25.0	30
24	130		26.5	
25	131		24.0	
23.5	129		23.5	
25.5	138		25.0	
28	146		25.0	
			25.5	
			28.0	
			29.0	
			28.5	
			14.0	

Copper tubes - third run

Average steam pressure - gauge	9.3 #
- corrected	10.7
- absolute	25.4
Quality of steam	95.0 %
Latent heat of vaporization at 25.4 #	950.8 B.T.U.
Boiling temperature at 25.4 #	240.9 °F
Average temperature of exhaust steam	165.9 °F
Gross weight condensed steam	326.5 #
Water added to condense steam	90.0 #
Net weight of condensed steam	236.5 #

Heat given up by steam cooling from 240.9 to 165.9 or 75 °F

236.5 x 75 - 17,700 B.T.U.

Heat given up by steam in condensing

236.5 x 0.95 x 950.8 - 213,600

Total B.T.U. given to evaporator 231,300

Water evaporated	189.5 #
Average vacuum in evaporator - gauge	24.7 " Hg
- corrected	24.3 " Hg
- # absolute	2.8 #
Latent heat of vaporization at 2.8 #	1014.1 B.T.U.
Boiling temperature at this pressure 2.8 #	138.4 °F

Heat used to raise water added to boiling point

180 # at	144 °F				180	x 5.6	- 1010
27.5	122	27.5	x 16.4	- 450			
25	129	25	9.4	236			
24	130	24	8.4	200			
25	131	25	7.4	184			
23.5	129	23.5	9.4	220			
25.5	138	25.5	0.4	10			
28	146			---	28	7.6	- 210
				1300			----
							1220

Heat to vaporize 189.5 # of water

189.5 x 1014.1 - 192,200 B.T.U.

Total B.T.U. 192,280

Efficiency 82.9 %

Tin tubes - first run

Time - Hours Minutes	Steam pressure Pounds - gauge	Vacuum Inches Hg	Temperature Exhaust steam
0:00	11.0	19.5	178
5	9.8	24.3	180
10	10.8	25.0	182
15	9.5	25.0	176
20	9.0	25.0	175
25	10.0	24.1	174
30	9.8	24.9	178
35	9.7	25.1	181
40	10.2	25.1	183
45	11.2	25.1	181
50	10.6	25.2	180
55	10.0	25.2	177
1:00	9.6	25.2	179
5	9.5	24.9	178
10	9.1	25.2	178
15	9.9	24.6	175
20	9.8	25.2	183
25	10.0	25.3	186
30	10.1	25.2	181
35	10.1	25.3	177
40	10.1	25.2	174
45	10.1	25.2	172
50	9.5	25.2	172
55	5.8	25.3	174
2:00	7.8	24.8	173

Water added at --- °F		Water removed	Condensed steam-gross	Cold water added to condense steam
180 # at	125.5 F	128	27	30
23.7	130		23.7	30
24.5	135		24.5	30
28.7	126.5		28.5	
29.5	123		28.7	
24.5	125.5		29.5	
			24.5	
			25.0	
			24.2	
			25.5	
			25.5	
			27.5	
			29.7	

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Tin tubes - first run

Average steam pressure - gauge	9.7	#
- corrected	11.1	
- absolute	25.8	
Quality of steam	95.0	%
Latent heat of vaporization at 25.8 #	950.2	B.T.U.
Boiling temperature of steam at this pressure	241.7	°F
Average temperature of exhaust steam	177.9	°F
Gross weight condensed steam	343.8	#
Water added to condense steam	90.0	
Net weight steam used	253.8	#

Heat given up by steam in cooling from 241.7 to 177.9 or 63.8 F

253.8 x 63.8 - 16,200 B.T.U.

Heat given up by steam in condensing

253.8 x 0.95 x 950.2 - 229,200

Total 245,400

Average vacuum in evaporator - gauge	25.2	" Hg
- corrected	24.8	" Hg
- # absolute	2.5	#
Latent heat of vaporization at 2.5 #	1017.0	B.T.U.
Temperature of steam at this pressure 2.5 #	133.8	°F
Total water added	310.9	#
Water removed	128.0	
Water evaporated	182.9	

Heat to raise added water to boiling temperature

180 at	125.5	180 x 8.3	- 1490	
23.7	130	23.7 x 3.8	90	
24.5	135			24.5 x 1.2 - 30
28.7	126.5	28.7 x 7.3	210	
29.5	123	29.5 x 10.8	320	
24.5	125.5	24.5 x 8.3	200	
			2310	30

Heat to vaporize water

182.9 x 1017 186950

Total 189,230 B.T.U.

Efficiency 77.1 %

Tin tubes - second run

Time - Hours Minutes	Steam pressure Pounds - gauge	Vacuum Inches Hg.	Temperature Exhaust steam
0:00	1.0	21.2	184
5	5.1	22.5	180
10	5.5	21.2	188
15	6.4	21.0	187
20	6.3	21.0	190
25	6.5	21.4	188
30	6.9	21.7	187
35	6.9	21.8	187
40	5.9	21.8	182
45	5.5	21.2	182
50	4.7	21.8	184
55	6.5	23.0	184
1:00	6.0	22.0	186
5	6.3	22.0	190
10	7.5	22.3	183
15	6.5	22.5	179
20	6.5	22.5	178
25	6.2	22.5	183
30	5.2	21.9	182
35	5.0	22.6	183
40	6.5	22.8	183
45	6.1	23.0	179
50	6.2	23.0	177
55	6.2	23.0	175
2:00	5.9	22.1	185

Water added at --- °F	Removed Water	Condensed steam	Water to condense steam
180 at 143 F	122 #	27.8 #	30 #
24.5		24.5	30
25.0		25.0	30
25		26.5	
27		25.0	
24		27.0	
24.5		22.0	
		23.5	
		27.0	
		24.0	
		22.0	
		24.7	
		28.5	
		27.0	
		27.0	

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Tin tubes - second run

Average steam pressure - gauge	5.9	#
- corrected	7.2	
- absolute	21.9	
Quality of steam	95.0	%
Latent heat of vaporization at 21.9 #	956.2	B.T.U.
Boiling temperature at 21.9 #	232.7	°F
Average temperature of exhaust steam	183.6	°F
Gross weight condensed steam	381.5	#
Water added	90.0	
Net weight steam used	291.5	

Heat given up by steam in cooling from 232.7 to 183.6 or 49.1 °F

291.5 x 49.1 - 14,300 B.T.U.

Heat given up by steam in condensing

291.5 x 956.2 x 0.95 - 264,800

Total 279,100 B.T.U.

Average vacuum in evaporator - gauge	22.1	" Hg
- corrected	21.7	" Hg
- # absolute	4.1	#
Latent heat of vaporization at 4.1 #	1005.0	B.T.U.
Temperature of steam at 4.1 #	153.9	°F

Heat to raise added water to the boiling point

180	at	143 F	180 x	10.9 -	1980
24.5		146	24.5	7.9	190
25		144	25	9.9	240
25		146	25	7.9	190
27		138	27	15.9	430
24		137	24	16.9	410
24.5		143	24.5	10.9	270
					3710

Water added	330.0 #
Water removed	122.0
Water evaporated	208.0

Heat to evaporate water

208 x 1005 - 209,000 B.T.U.

Total 212,700 B.T.U.

Efficiency 76.2 %

Steel tubes -first run

Time - Hours Minutes	Steam pressure Pounds - gauge	Vacuum Inches Hg.	Temperature Exhaust steam
0:00	4.6	21.3	164
5	4.8	22.1	168
10	6.1	23.2	171
15	7.0	23.0	167
20	6.5	22.8	169
25	6.6	21.9	171
30	6.8	22.1	173
35	7.6	22.1	176
40	7.9	22.2	170
45	8.0	22.4	168
50	7.8	22.1	165
55	7.4	21.8	166
1:00	7.2	22.0	169
5	7.5	22.1	170
10	9.0	22.1	170
15	8.3	22.4	172
20	7.1	22.3	173
25	6.7	22.4	169
30	6.8	22.1	173
35	7.2	22.6	171
40	7.3	22.5	170
45	7.1	22.7	169
50	6.9	22.7	170
55	7.3	22.7	170
2:00	7.1	22.3	169

Water added		Water Removed	Condensed Steam - gross	Water added to condense steam
180 # at	140 °F			
26.5	130	107 #	26.5 #	30 #
22.5	138		22.5	30
28	142		25.6	30
27	137		28	30
21.5	135		27	
26.7	139		21.5	
28	140		26	
29.2	141		26.7	
22	135		29.5	
			27.7	
			28	
			23.8	
			29.2	
			26.5	
			22	

Steel tubes - first run

Quality of steam	95.0 %
Average steam pressure - gauge	7.1 #
- corrected	8.4
- absolute	23.1
Average temperature exhaust steam	169.8 °F
Latent heat of vaporization at 23.1 #	954.4 B.T.U.
Temperature of steam at 23.1 #	235.7 °F
Gross weight of condensed steam	390.5 #
Weight water added	120.0
Net weight steam used	270.5

Heat given up by steam in cooling from 235.7 F to 169.8 or 65.9 F

270.5 x 65.9 - 17,800

Heat given up by steam in condensing

270.5 x 0.95 x 954.4 - 245,100

Total heat 262,900 BTU

Average vacuum in evaporator - gauge	22.3 " Hg
- corrected	22.0
- absolute	3.9 #
Temperature at 3.9 #	151.9 °F
Latent heat of vaporization at 3.9 #	1006.2 B.T.U.
Water added	311.4 #
Water removed	107.0
Water evaporated	204.4

Heat to raise added water to boiling point

180 # at	140	180 x	11.9	-	2160
26.5	130	26.5	22.9		600
22.5	138	22.5	13.9		310
28	142	28	9.9		280
27	137	27	14.9		400
21.5	135	21.5	16.9		360
26.7	139	26.7	12.9		340
28	140	28	11.9		340
29.2	141	29.2	10.9		320
22	135	22	16.9		370

					5480 B.T.U.

Heat to vaporize water

204.4 x 1006.2 205500

Total 210980 B.T.U.

Efficiency 80.2 %

Steel tubes - second run

Time - Hours Minutes	Steam Pressure Pounds - gauge	Vacuum Inches Hg.	Temperature Exhaust steam
0:00	4.2	23.2	172 °F
5	6.8	23.0	174
10	6.5	23.2	176
15	7.2	23.2	175
20	6.8	22.8	170
25	7.1	22.9	176
30	7.0	23.0	174
35	8.0	23.3	168
40	6.9	23.2	170
45	8.2	23.3	178
50	7.5	22.9	177
55	7.3	23.1	171
1:00	7.6	23.2	173
5	5.2	22.2	169
10	6.6	23.3	166
15	7.2	23.3	173
20	6.8	23.2	172
25	7.6	23.3	170
30	7.3	23.3	172
35	6.5	23.1	170
40	6.6	23.2	171
45	6.9	23.3	174
50	7.6	23.2	170
55	7.0	23.2	172
2:00	6.9	23.1	172

Water added		Water removed	Condensed steam - gross	Water for condensing steam
180 #	at 143 °F	115.2 #	25.5	30
24.5	150		24.5	30
26	146		28.2	30
27.5	148		23.7	30
28.2	135		23	
26	140		26	
27	141		27	
			24.7	
			25.	
			26.5	
			27.2	
			25.5	
			29	
			28.2	
			25	
			29	

Steel tubes - second run

Average steam pressure	- gauge	6.9 #
	- corrected	8.3
	- absolute	23.0
Quality of steam		95.0 %
Average temperature of exhaust steam		172.0 °F
Latent heat of vaporization at 23 #		954.4 B.T.U.
Temperature of steam at 23 #		235.5 °F
Weight of condensed steam-gross		418.0 #
Water added		120.0
Steam used		298.0

Heat given up by steam cooling from 235.5 to 172 F or 63.5 F

298 x 63.5 - 18,900 B.T.U.

Heat given up by steam condensing

298 x 0.95 x 954.4 - 270,100

Total 289,000 B.T.U.

Average vacuum in evaporator	- gauge	23.1 " Hg
	- corrected	22.8
	- absolute	3.5 #
Latent heat of vaporization at 3.5 #		1008.3 B.T.U.
Temperature of steam at 3.5 #		147.2 °F
Water added		339.2 #
Water removed		115.2
Water evaporated		224.0

Heat to raise added water to boiling point

180 # at	143	180 x	4.2 -	750				
24.5	150				24.5 x	2.8 -	70
26	146	26	1.2	30			
27.5	148				27.5	0.8	20
28.2	135	28.2	12.2	340			--
26	140	26	7.2	190			90
27	141	27	6.2	170			

				1480			

Heat to vaporize water

224 x 1008.3 - 225,600

Total 227,000 B.T.U.

Efficiency 78.7 %

Lead tubes - first run

Time - Hours Minutes	Steam pressure Pounds - gauge	Vacuum Inches Hg.	Temperature Exhaust steam
0:00			
5	7.2	22.2	160
10	8.5	23.5	150
15	8.5	24.0	149
20	8.0	23.9	147
25	3.8	24.9	148
30	5.1	23.0	149
35	4.9	22.1	149
40	4.6	23.0	148
45	4.6	23.1	147
50	4.9	23.0	147
55	5.2	22.6	149
1:00	7.5	23.1	147
5	8.5	23.5	148
10	8.1	23.2	148
15	9.0	23.5	149
20	9.0	23.2	149
25	9.1	23.1	150
30	9.0	23.5	148
35	8.8	23.2	149
40	9.0	23.5	149
45	9.0	22.8	149
50	9.0	23.5	148
55	10.5	23.5	149
2:00	10.5	27.5	149

Water added # at ^{o}F		Water removed	Condensed steam - gross	Cold water added
180 # at	135 F	137 #	24.0 #	30 #
24	127		24.0	30
23.7	127		25.8	
27.0	129		26.1	
28	131		23.7	
21.5	131		27.0	
28	138		26.0	
27	131		28.0	
27	130		21.5	
27.5	129		28.0	
27	135		27.0	
			24.0	
			27.0	
			27.5	
			27.0	
			23.5	
			24.0	
			22.8	
			8.1	

Lead tubes - first run

Average steam pressure - gauge	7.3	#
- corrected	8.7	
- absolute	23.4	
Latent heat of vaporization at 23.4	953.3	B.T.U.
Temperature of steam at this pressure	236.0	°F
Quality of steam	95.0	%
Total condensed steam	465.0	#
Water added	60.0	
Condensed steam - net	405.0	
Average temperature exhaust steam	149.0	°F

Heat given up by steam in cooling from 236 to 149 or 87 °F

405 x 87 - 35,200 B.T.U.

Heat given up by steam in condensing

405 x 0.95 x 953.3 - 366,700

Total 401,900 B.T.U.

Average vacuum in evaporator - gauge	23.3	" Hg
- corrected	23.0	
- absolute	3.5	# abs.
Latent heat of vaporization at 3.5 #	1009.0	B.T.U.
Temperature of steam at 3.5 #	147.7	°F
Total water added	440.7	#
Total water removed	137.0	
Water evaporated	303.7	

Heat to raise added water to boiling point

180 #	at 135 F	180	x 12.7	-	2285
24	127	24	20.7		497
23.7	127	23.7	20.7		492
27.0	129	28	18.7		524
28.	131	21.5	16.7		360
21.5	131	27	16.7		451
28	138	28	9.7		272
27	131	27	17.7		478
27	130	27	18.7		505
27.5	129	27.5	18.7		515
27	135	27	12.7		343

					6720 B.T.U.

Heat to vaporize water

303.7 x 1009 - 306400

Total 313,100

Efficiency 78.1 %

Lead tubes - second run

Time - Hours Minutes	Steam pressure Pounds - gauge	Vacuum Inches - Hg.	Temperature Exhaust steam
0:00			
5	8.2	23.3	157
10	7.3	21.8	151
15	7.5	24.0	147
20	7.2	24.5	148
25	7.5	24.0	151
30	7.3	23.3	147
35	7.0	24.1	148
40	7.0	24.0	148
45	7.0	23.5	151
50	7.3	23.3	149
55	7.1	23.9	148
1:00	7.9	23.2	148
5	6.1	23.3	150
10	6.4	23.7	149
15	7.0	23.2	151
20	7.3	22.0	152
25	7.4	22.9	152
30	8.0	22.8	151
35	7.3	23.0	151
40	7.3	22.8	152
45	7.3	23.0	156
50	9.0	23.6	153
55	9.7	23.0	148
2:00	3.0	23.3	146

Water added # at °F		Water removed	Condensed steam - gross	Cold water added to condense steam
180 # at	148 F	163 #	28.5 #	30 #
21.5	122		21.5	25
26.5	125		26.5	
23.5	130		24.5	
22.7	135		22.7	
29.0	136		29.0	
26.0	140		26.0	
26.5	142		26.5	
27.0	133		25.5	
29.0	142		27.0	
			29.0	
			30.0	
			24.5	
			36.0	

Lead tubes - second run

Average steam pressure - gauge	7.3 #
- corrected	8.7
- absolute	23.4
Latent heat of vaporization at 23.4 #	953.3 B.T.U.
Temperature of steam at this pressure	236.0 °F
Quality of steam	95.0 %
Temperature of exhaust steam	151.0 °F
Gross weight condensed steam	377.2 #
Water added	55.0
Net weight of water	322.2

Heat given by steam cooling from 236 to 151 or 85 °F

322.2 x 85 - 27,400 B.T.U.

Heat given up by steam in condensing

322.2 x 0.95 x 953.3 - 291,800

Total 319,200

Average vacuum in evaporator - gauge	23.3 " Hg
- corrected	23.0 " Hg
- absolute	3.5 #
Latent heat of vaporization at 3.5 #	1009.0 B.T.U.
Temperature of steam at 3.5 #	147.7 oF
Water added	411.7 #
Water left	163.0
Water evaporated	248.7

Heat to raise added water to boiling point

180 #	at 148 F	180	x 0.3	- 54
21.5	122	21.5	25.7	553
26.5	125	26.5	22.7	603
23.5	130	23.5	17.7	435
22.7	135	29	12.7	370
29	136	22.7	11.7	244
26	140	26	7.7	170
26.5	142	26.5	5.7	160
27	133	27	14.7	390
29	142	29	5.7	180
				3160 B.T.U.

Heat to vaporize water

248.7 x 1009 - 250900

Total 254,000

Efficiency 79.5 %

The average results of this series of tests may be summed up as follows,copper tubes,efficiency 83.4 %;steel tubes,efficiency 79.5 %;tin tubes,efficiency 76.7 % and lead tubes,efficiency 78.6 %. With the copper tubes,one of the runs gave an efficiency of 85.2 %,much above the average of the other two runs. This was thought to be due to a leak in the steam connections which allowed a small quantity of steam to mix with the water in the evaporator. At the close of this run,the end plates were taken off and the cast iron plates holding the tubes tightened. In the next run, the efficiency dropped to the lower value.

From the above results it may be seen that the efficiency is highest for the copper tubes and next highest for the steel tubes. These results would be expected,inasmuch as copper and steel have a higher coefficient of heat transmission than the other materials used,and also from the fact that the copper and steel tubes were from one-third to one-fourth as thick as the other two sets of tubes. The difference in the efficiency of the copper and of the steel is not as great as might be expected from the difference in their heat conductivities. This is,doubtless,due to the fact that both tubes were very thin.

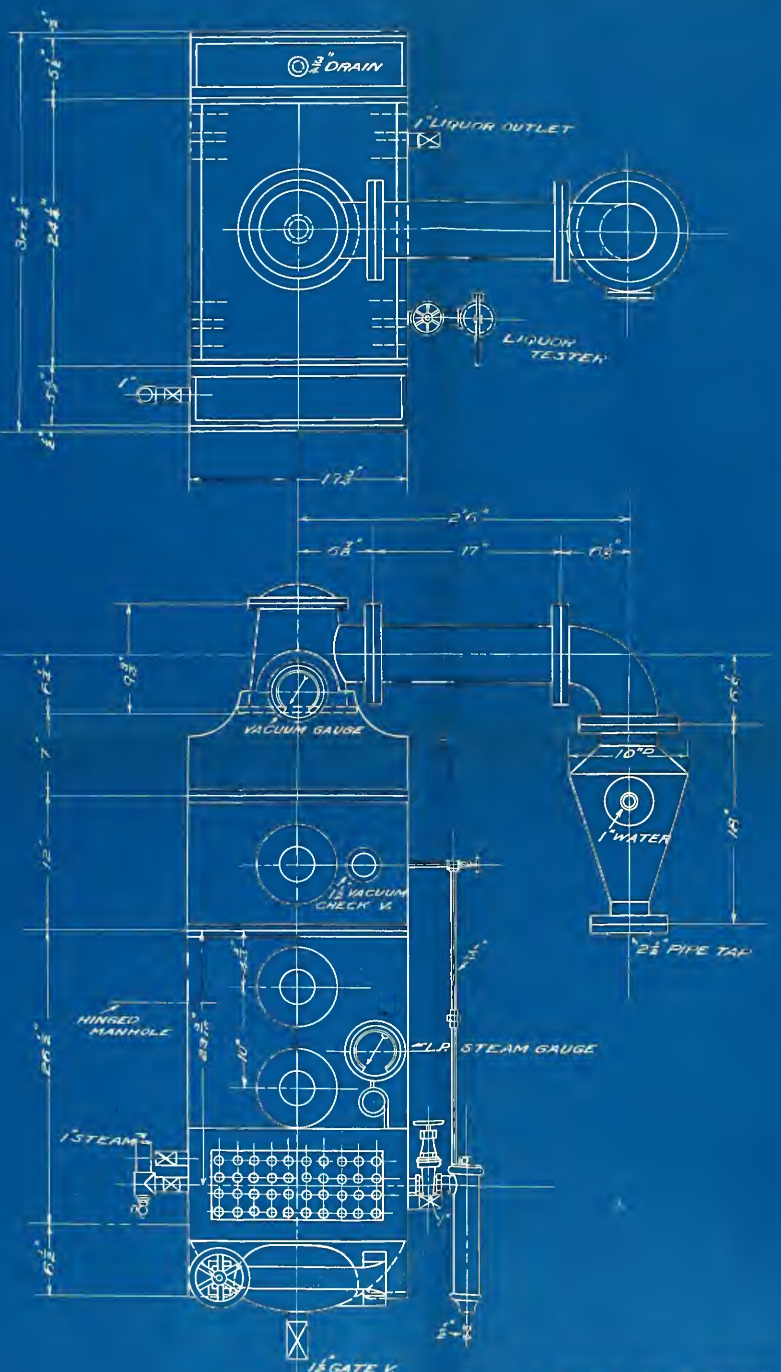
The relation of the efficiencies of the lead and tin tubes are somewhat harder to explain. Although the coefficient of heat transmission for tin is greater than that of lead,and although the lead tubes were about one-eighth thicker,the efficiency of the latter is greater. It may also be noted in this connection that the exhaust steam came out at a lower temperature in the case of the lead tubes,than of the tin. Unless there is some unknown error in these determinations we are unable to account for these facts.

In general, it may be said that there is very little difference in the efficiencies for the various tubes, the maximum difference being 6.7 %. This is doubtless due to the fact that, with tubes of this small thickness the coefficient of heat transmission does not materially affect the efficiency. This figure may be altered one way or the other, by changing the velocity of the steam, as the first runs made show. These runs were not recorded as the evaporator was not run at anything near its capacity. In the recorded runs the steam velocity was kept as near the same as possible by a proper regulation of valves.

In conclusion, it may be stated that a more extended series of tests should be made, if it is desired to obtain results of any great commercial value.

H C Dormitzer

E. [illegible]



ARMOUR INSTITUTE OF TECHNOLOGY

SINGLE EFFECT
SWENSON EVAPORATOR

MAY 21, 1912 SCALE 1 1/2" = 1'
DRAWN BY J.H.Dormitzer
ROLESON-DORMITZER, THESIS

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